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The Revised Solar Array Synthesis Computer Program

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FOREWORD

The Revised Solar Array Synthesis Computer Program is a general-purpose program which computes solar array output characteristics while accounting for the effects of temperature, incidence angle, charged-particle irradiation, and other degradation effects on various solar array configurations in either circular or elliptical orbits. Array configurations may consist of up to 75 solar cell panels arranged in any series-parallel combination not exceeding three series-connected panels in a parallel string and no more than 25 parallel strings in an array. Up to 100 separate solar array current-voltage characteristics, corresponding to 100 equal-time increments during the sunlight illuminated portion of an orbit or any 100 user-specified combinations of incidence angle and temperature, can be computed and printed out during one complete computer execution. Individual panel incidence angles may be computed and printed out at the user's option.

Technical direction and consultation during the development of the computer program was provided by Mr. Obenchain, Contract Technical Officer, Power Systems Design Section, National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, Maryland. Technical direction at RCA was the responsibility of Mr. P. Pierce. Mr. P. Hyland of RCA was responsible for computer programming.

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SECTION I

GENERAL

The Revised Solar Array Synthesis Computer Program is based upon an original solar array synthesis program developed by RCA and described in GSFC Technical Report No. X-716-69-390. Two major differences exist between the two programs. The first is that the revised program has the capability to compute solar cell array current-voltage characteristics for solar cell panels connected in series, as well as in parallel. Secondly, the revised program enables calculation of individual panel incidence angles for a variety of array configurations designed for missions in circular or elliptic type earth orbits. Other minor differences such as number of solar panels per array, increased number of array computations per computer execution, and increased versatility with panel incidence angles versus solar cell cover-glass thicknesses versus relative short-circuit current of solar cells are characteristic of the revised synthesis program. A second computer program (Power Systems Computer Program) developed under the same contract will use the solar array synthesis output to perform energy balance calculations for various photovoltaic power system configurations.

Like the original synthesis program, the Revised Solar Array Synthesis Computer Program is written in Fortran IV language for use on the IBM computer and has the purpose of computing and printing out solar cell array I-V characteristics. Solar cell degradation factors such as temperature, charged particle irradiation, isolation and bypass diode voltage losses, and series resistance are taken into account during all array computations. Up to 100 separate solar array I-V characteristics, corresponding to 100 equal-time increments during the sunlight illuminated portion of an orbit or any 100 user-specified combinations of incidence angle and temperature, can be computed and printed out during one complete execution.

In the revised program, an array configuration may be defined as planar (Nimbus type), faceted, or circular and may consist of up to 75 solar cell panels arranged in any series-parallel combination not exceeding three series-connected panels in a parallel string and no more than 25 parallel strings in an array. (See Figure 1.) Each panel in a parallel string must have the same number of parallel solar cell strings, but the number of series-connected solar cells may differ for each panel. Separate user-defined profiles of panel temperature versus time versus sun angle are provided for in the program, as well as profiles of panel incidence angle versus time versus sun angle. Panel incidence angles may be computed and printed out at the user's option.

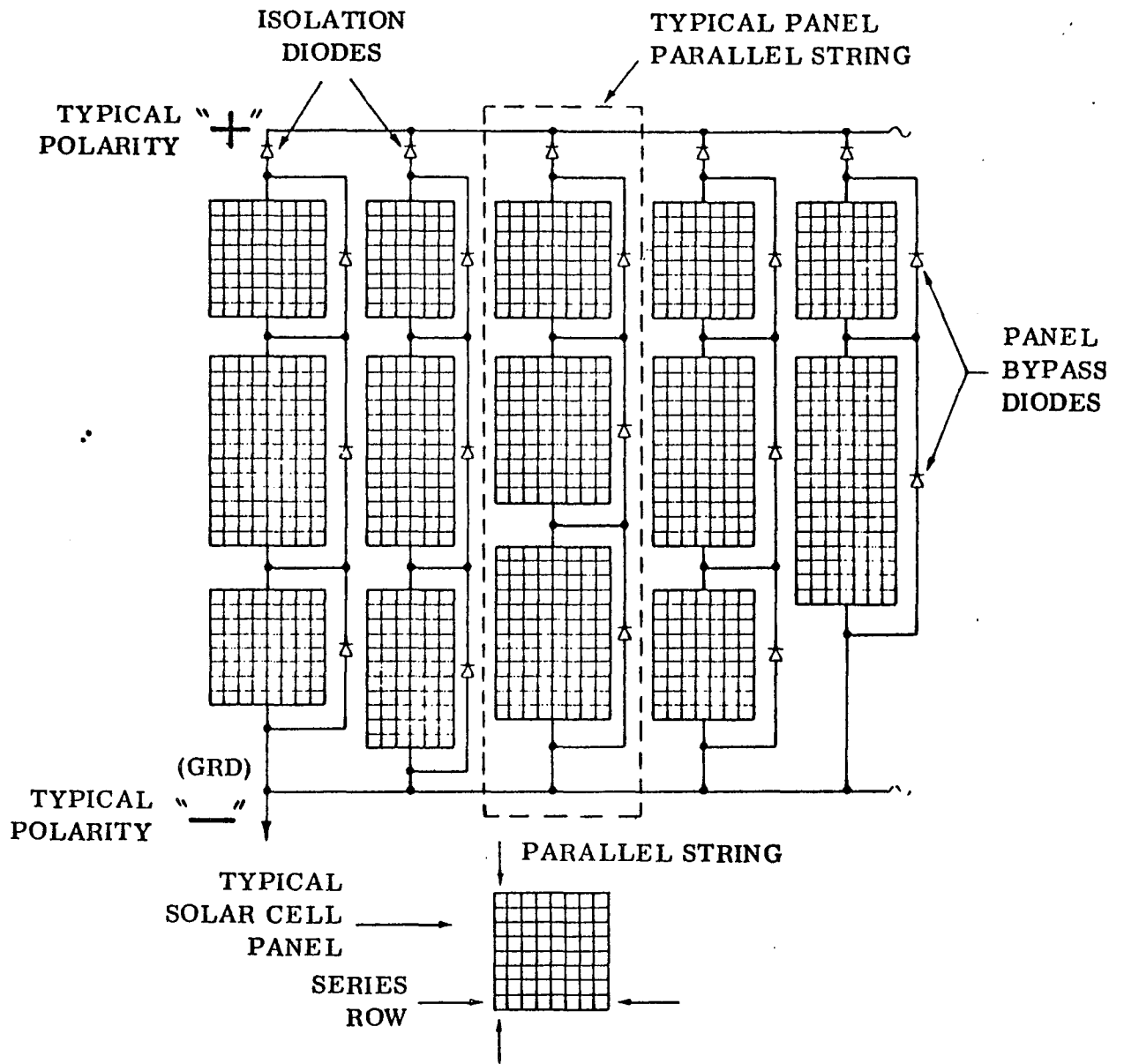


Figure 1. Solar Array Layout

Economical execution of the program results through using only those program subroutines required for a specific set of run conditions. The program user may elect to perform solar cell calculations only, or solar cell and solar array calculations. Any number of runs may be chained together to evaluate the effects of specific or numerous parameter changes.

The revised solar array program has six parts - one main routine from which five subroutines are called. The six program parts are:

MAIN - reads input data, performs parameter initialization, calls subroutines as required, computes and stores I-V characteristics for up to 75 panels, computes resulting solar array I-V characteristics in 1-volt increments, prints output data, and punches a two-argument solar array STINT table for use in the Power Systems Computer Program.

PHI - computes damage-equivalent, normally incident (deni) 1-MeV electron fluxes for each of several kinds of charged omnidirectional particles (electrons, protons, solar-flare protons and solar-flare alpha particles) while accounting for solar cell cover-glass and back-shielding thicknesses, sums the individual fluxes into a daily flux, and calculates total mission flux based on the mission duration in days.

DEGRAD - 1.0 or 10.0 ohm-cm base resistivity solar cell I-V curve input is degraded for deni 1-MeV electron flux calculated in Subroutine PHI or by a user specified deni 1-MeV electron flux value.

STASH - degrades, stores, and prints solar cell input I-V characteristics from Subroutines DEGRAD or STINT for current and voltage degradation factors and series resistance effects for up to 15 specified temperatures.

STINT - a table storage subroutine adapted from the IBM SHARE library STINT routine which supplies on command, the values of variables which are functions of one, two, or three arguments.

INCANG - computes individual panel incidence angles from angle and time data supplied by the MAIN routine for spinning or one revolution per orbit (RPO) spacecraft solar array configurations in an elliptical or circular earth orbit.

PROGRAM DESCRIPTION

Because of the many types of computations required in the execution of the Revised Solar Array Synthesis Program, the program is divided into a main routine, called MAIN, and the following subroutines: PHI, DEGRAD, STASH, STINT, and INCANG. Instructions to the computer are entered by means of computer NCODE instruction cards. NCODE names are shown where the described function or value is used as a computer NCODE instruction.

A. MAIN - COMPUTER PROGRAM CONTROL

The primary purpose of MAIN is to perform all data input and NCODE parameter initialization, print out the input data used (printed out in an E format), call out the other subroutines when they are required, and perform the solar array calculations. MAIN will also print out calculated panel incidence angles (NCODE NWRIT) and punch (NCODE NPUNCH) a two-argument STINT table containing solar array I-V characteristics at the specified time increments.

Up to 100 separate solar array I-V characteristics, corresponding to 100 equal time increments during the sunlight portion of an orbit or any 100 specified combinations of incidence angles and temperatures, can be computed during one computer execution.

The first function of the MAIN routine is to initialize and read all input parameters contained in the NCODE's and data tables. Subroutines PHI and DEGRAD are called, if applicable, to degrade the input solar cell I-V curve for charged-particle irradiation. Additional design degradation factors such as series wiring losses and measurement errors are applied to the radiation degraded solar cell curve in subroutine STASH at the same time STASH is expanding the cell curve into a family of 15 I-V curves spanning the user-specified temperature range of interest for the ensuing array calculations.

Solar array calculations are initiated in MAIN with the contribution to the total solar array I-V curve of each of up to 25 panel parallel strings calculated individually. An equivalent cell I-V curve is constructed for each string based upon the temperature and incidence angle profile of each panel in the string. The total string current and voltage values are calculated by multiplying the representative cell's current values by the number of parallel solar cell strings and the voltage values by the number of active solar cells connected in series. Each panel in a parallel string must have the same number of parallel solar cell strings, but the number of series-connected solar cells may differ for each panel. Losses of

voltage due to voltage drops across user-specified parallel string isolation diodes and those panel bypass diodes which are back-biased because of inactive series connected panels are calculated into the string I-V curve. Summation of the individual string I-V curves yields the total solar array I-V curve at each time increment.

Maximum solar array power is computed from the final array I-V curve. If two identical maximum power points are calculated, the subsequent power point characteristics of power (watts), voltage (volts), and current (amps) are saved. Time is incremented after maximum power point calculations are completed and the complete solar array is recalculated accounting for those parameters effected by time. A STINT table containing all array I-V characteristics for each time increment may be automatically punched into a set of STINT table cards by the computer by initializing NCODE NPUNCH. The computer will automatically count and punch the total number of argument 1 and argument 2 values on the table header card. (See Section III.)

The inclusion of solar cell panels connected in series in an array configuration with each panel having its own temperature versus time and incidence angle versus time profile will introduce current limiting effects. If a series-connected panel has a greater incidence angle than other series-connected panels in a panel string, the entire panel string output current will be limited to the short-circuit current of the low-output panel. A condition also exists where one of the panels may be in total darkness and, therefore, limiting the entire panel string to zero output. This condition is avoided by providing a bypass diode in parallel with each series panel, which results under the above described condition in a loss of the voltage output from the bypassed panel and a voltage loss to the remaining active series panels equivalent to the bypass diode voltage drop.

There are occasions, however, where the program user may divide a panel circuit into two or three parts to obtain more accurate solar array output characteristics and not have bypass diodes for each of the circuit subpanels. An example of this might be a circular array configuration where each parallel row of solar cells in each panel circuit has a different incidence angle and theoretically a different temperature profile. The computer program will accept series-connected panels without bypass diodes. However, if any one of the subpanels becomes inactive, then the entire panel series string output is set to zero. The programmer may vary the number of series connected solar cells per subpanel in order to determine the maximum array output for the desired orbit.

B. PHI - CALCULATION OF DENI 1-Mev ELECTRON FLUX

The purpose of the subroutine PHI^{1,2} is to calculate the amount of damage-equivalent normally incident (deni) 1-MeV electron flux to which the input solar cell will be exposed during its lifetime. This can also be inputted as a user-defined constant (NCODE FLUX) in which case PHI is skipped. The deni 1-MeV electron flux of charged particles (electrons, protons, solar flare protons, and solar flare alphas) is calculated separately, and the total daily flux is obtained by summation. Total mission fluxes are calculated in PHI when NCODE DAYS is given a value greater than 1.0. NCODE DAYS must never be set to zero. Control is then returned to MAIN.

Charged-particle population is tabulated in ranges of millions of electron volts (MeV) and assigned to an energy range number. Tables 1 through 4 present sample data for the specified energy ranges. Where no particle population is considered, a value of zero must be used. See Section III for proper STINT table preparation.

TABLE 1. ELECTRON FLUX FORMAT

Energy Range Number	ΔE (Mev)	Electrons/cm ²
1	0.0-0.25	1.28E15
2	0.25-0.50	3.62E14
3	0.50-0.75	1.0E14
4	0.75-1.0	3.11E13
5	1.0-2.0	1.32E13
6	2.0-3.0	1.21E11
7	3.0-4.0	4.7E9
8	4.0-5.0	3.61E9
9	5.0-6.0	3.6E9
10	6.0-7.0	1.22E9
11	>7.0	0

TABLE 2. PROTON FLUX FORMAT

Energy Range Number	ΔE (Mev)	Protons/cm ²
1	0.0-1.0	4.38E15
2	1.0-2.0	3.4E12
3	2.0-3.0	1.2E11
4	3.0-4.0	2.48E9
5	4.0-5.0	4.38E8
6	5.0-6.0	2.92E8
7	6.0-7.0	2.92E7
8	7.0-8.0	2.42E7
9	8.0-9.0	7.3E6
10	9.0-10.0	5.84E6
11	10.0-11.0	5.84E6
12	11.0-12.0	5.84E6
13	12.0-13.0	5.84E6
14	13.0-14.0	5.84E6
15	14.0-15.0	5.84E6
16	15.0-30.0	1.75E6
17	30.0-100.0	7.3E3
18	>100.0	7.4E3

Program user-specified cover glass shielding (NCODE CG) and backshielding (NCODE BS) are also used by subroutine PHI. Cover glass shielding values are normally inputted in terms of mils of fused silica ranging from 0 to 54 mils. Maximum cover glass thickness may go as high as 1200 mils. Backshielding thicknesses may range from 0 to 1000 mils of aluminum (1000 mils of aluminum is used to approximate infinite backshielding). Any desired thickness of cover glass or backshielding within the limits described above may be specified by the user.

TABLE 3. SOLAR-FLARE PROTON FLUX FORMAT

Energy Range Number	ΔE (Mev)	Protons/cm ²
1	0.0-1.0	0
2	1.0-2.0	6.0E10
3	2.0-3.0	1.5E10
4	3.0-4.0	8.0E9
5	4.0-5.0	4.5E9
6	5.0-6.0	2.5E9
7	6.0-7.0	2.0E9
8	7.0-8.0	1.1E9
9	8.0-9.0	7.0E8
10	9.0-10.0	4.5E8
11	10.0-11.0	4.0E8
12	11.0-12.0	4.0E8
13	12.0-13.0	4.0E8
14	13.0-14.0	3.0E8
15	14.0-15.0	2.5E8
16	15.0-30.0	1.8E9
17	30.0-100.0	1.7E9
18	>100.0	2.0E8

Each energy range number is related to a damage factor whose magnitude depends on the type of charged particle and shielding value. These damage factors are listed in Tables 5, 6, and 7. Table 8 lists the stored shielding densities and equivalent thicknesses of fused silica cover-glass and aluminum backshielding.

TABLE 4. SOLAR-FLARE ALPHA PARTICLE FLUX FORMAT

Energy Range Number	ΔE (Mev)	Alpha Particles/ cm ²
1	16-18	4.0E7
2	18-20	3.0E7
3	20-22	3.0E7
4	22-25	3.0E7
5	25-30	4.0E7
6	30-32	2.0E7
7	32-35	2.0E7
8	35-40	2.0E7
9	40-45	2.0E7
10	45-47	1.0E7
11	47-52	1.2E7
12	52-57	1.3E7
13	57-60	5.0E6
14	60-80	3.2E7
15	80-100	2.0E7
16	100-200	2.25E7
17	200-400	4.5E6
18	>400	1.0E6

C. DEGRAD - IRRADIATION DEGRADATION OF SOLAR CELL I-V CHARACTERISTICS

In subroutine DEGRAD^{1,2} the solar cell I-V characteristics stored in subroutine STINT as current and voltage vectors, called XIVEC and VVEC, are degraded for radiation damage by empirical equations. The total deni 1-MeV electron flux in this calculation is an input parameter from either subroutine PHI or NCODE FLUX, along with the solar cell base resistivity NCODE BOHMS (1.0 or 10.0 ohm-cm).

TABLE 5. DAMAGE FACTORS FOR ELECTRONS

Energy Range Number	Shielding Number						
	0.0	1.0	1.5	3.0	6.0	9.0	200.0
1	0.01	0.0	0.0	0.0	0.0	0.0	0.0
2	0.06	0.03	0.02	0.0	0.0	0.0	0.0
3	0.18	0.13	0.08	0.03	0.0	0.0	0.0
4	0.38	0.30	0.20	0.10	0.02	0.0	0.0
5	1.3	1.15	1.02	0.75	0.47	0.25	0.0
6	2.9	2.70	2.50	2.05	1.55	1.10	0.0
7	4.35	4.15	3.92	3.38	2.85	2.15	0.0
8	5.5	5.30	5.15	4.60	4.10	3.30	0.0
9	6.5	6.15	6.10	5.70	5.30	4.60	0.0
10	7.4	7.30	7.30	6.80	6.50	5.85	0.0
11	7.8	7.80	7.80	7.70	7.50	7.0	0.0

D. STASH - DEGRADATION AND TEMPERATURE EXPANSION OF SOLAR CELL I-V CHARACTERISTICS

The purpose of Subroutine STASH³ is to receive a set of I-V characteristics for a single solar cell at a temperature defined by NCODE TNOT, degrade it for current and voltage degradation effects (NCODES DI 1 through DI 4 and DV 1 and DV 2 respectively), and expand it into a family of curves for 15 equally spaced (NCODE DELTT) temperatures. Current and voltage temperatures coefficients are established in NCODES SIGISC and SIGVOC respectively. AVOCO is the NCODE for the open-circuit voltage of the input, undegraded solar cell while NCODE THETA is the open-circuit voltage degradation factor. NCODE AVPMO is the undegraded input solar cell maximum power point voltage and NCODE AIPMO is the maximum power point current.

Subroutine STASH prints a list of 50 current-voltage pairs at each of the 15 temperatures along with maximum power point values with associated maximum power current and voltage values, and ISC and OCV values. There I-V pairs are also stored for ready reference when solar cell information is called for by MAIN.

TABLE 6. DAMAGE FACTORS FOR PROTONS

Energy Range Number	Shielding Number							
	0.0	0.5	1.0	1.5	3.0	6.0	9.0	200.0
1	20000.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	10000.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	7000.0	6000.0	0.0	0.0	0.0	0.0	0.0	0.0
4	5400.0	5400.0	0.0	0.0	0.0	0.0	0.0	0.0
5	4500.0	4500.0	3000.0	0.0	0.0	0.0	0.0	0.0
6	3900.0	3900.0	3700.0	2000.0	0.0	0.0	0.0	0.0
7	3500.0	3500.0	3500.0	3100.0	0.0	0.0	0.0	0.0
8	3100.0	3100.0	3100.0	3100.0	200.0	0.0	0.0	0.0
9	2800.0	2800.0	2800.0	2800.0	1400.0	0.0	0.0	0.0
10	2700.0	2700.0	2700.0	2700.0	2000.0	0.0	0.0	0.0
11	2600.0	2600.0	2600.0	2600.0	2100.0	0.0	0.0	0.0
12	2500.0	2500.0	2500.0	2500.0	2100.0	100.0	0.0	0.0
13	2500.0	2500.0	2500.0	2500.0	2100.0	1000.0	0.0	0.0
14	2500.0	2500.0	2500.0	2500.0	2000.0	1400.0	0.0	0.0
15	2500.0	2500.0	2500.0	2500.0	2000.0	1500.0	100.0	0.0
16	2500.0	2500.0	2500.0	2500.0	2000.0	1800.0	1500.0	0.0
17	2300.0	2300.0	2300.0	2300.0	2000.0	2000.0	2000.0	0.0
18	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	0.0

Subroutine STASH spreads the solar cell I-V characteristics over the specified temperature range using a linear interpolation method. This procedure is based on solar cell temperature coefficient data obtained in the temperature range -60°C to $+80^{\circ}\text{C}$ and is considered accurate within these limits. Reasonable accuracy has been obtained with this program at temperature range extremes of -170°C and $+100^{\circ}\text{C}$ by assuming linear temperature coefficients within this range.

TABLE 7. DAMAGE FACTORS FOR ALPHA PARTICLES

Energy Range Number	Shielding Number						
	0.0	1.0	1.5	3.0	6.0	9.0	200.0
1	20000.0	10000.0	0.0	0.0	0.0	0.0	0.0
2	15000.0	13000.0	0.0	0.0	0.0	0.0	0.0
3	14500.0	14000.0	7000.0	0.0	0.0	0.0	0.0
4	13700.0	13700.0	11000.0	0.0	0.0	0.0	0.0
5	12500.0	12500.0	12000.0	0.0	0.0	0.0	0.0
6	11500.0	11500.0	11500.0	2500.0	0.0	0.0	0.0
7	11000.0	11000.0	11000.0	5200.0	0.0	0.0	0.0
8	10400.0	10400.0	10400.0	7200.0	0.0	0.0	0.0
9	9800.0	9800.0	9800.0	7900.0	0.0	0.0	0.0
10	9500.0	9500.0	9500.0	8000.0	1700.0	0.0	0.0
11	9500.0	9500.0	9500.0	7800.0	3650.0	0.0	0.0
12	9500.0	9500.0	9500.0	7700.0	5300.0	0.0	0.0
13	9500.0	9500.0	9500.0	7600.0	5700.0	1600.0	0.0
14	9400.0	9400.0	9400.0	7600.0	6300.0	4000.0	0.0
15	9200.0	9200.0	9200.0	7600.0	7000.0	6400.0	0.0
16	8600.0	8600.0	8600.0	7700.0	7400.0	7100.0	0.0
17	7000.0	7000.0	7000.0	7000.0	7000.0	7000.0	0.0
18	4000.0	4000.0	4000.0	4000.0	4000.0	4000.0	0.0

E. STINT - DATA STORAGE AND RETRIEVAL

Subroutine STINT is used many times throughout the program to obtain information from input data tables and the panel temperature and incidence angle profile tables. The name stands for Standard Table Interpolation; it is an adoption of the STINT routine which is a part of the IBM SHARE library.

The purpose of this routine is to store in tables, then supply on command, the values of variables which are functions of one, two, or three arguments. A package of STINT tables consists of a stack of individual table card decks, each

TABLE 8. SHIELDING NUMBERS

Shielding Density (gm/cm ²)	0.0	0.016	0.033	0.05	0.1	0.2	0.3	*
Equivalent mils of fused silico cover glass	0.0	3.0	6.0	9.0	18.0	36.0	54.0	1200.0
Equivalent mils of Aluminum	0.0	2.5	5.0	7.5	15.0	30.0	45.0	1000.0*
Shielding Number for Computer Lookup	0.0	0.5	1.0	1.5	3.0	6.0	9.0	200.0
*Simulates infinite backshielding								

beginning with a descriptive header card. In the loading mode, STINT will load such cards until it finds a blank card instead of a header. It will then exit back to the control point. The first use of the STINT routine, which occurs in MAIN, is to load all data tables.

Subroutines PHI and DEGRAD are essentially the same as those used in the MOPS Power System Computer Program, developed for NASA-MSC by RCA under Contract No. NAS 9-5266. A detailed technical discussion of the techniques employed in these two subroutines is contained in References 1 and 2. Subroutine STASH is essentially the same as Subroutine STASH used in the Nimbus B Energy Balance Computer Program, developed for NASA-GSFC by RCA under Contract No. NAS 5-9668. The techniques employed by STASH are described in Reference 3.

F. INCANG - CALCULATION OF PANEL INCIDENCE ANGLES

In Subroutine INCANG, individual panel incidence angles are calculated from angle and time data supplied by the MAIN routine. Incidence angles are calculated for solar array configurations of planar, faceted, or circular in circular or elliptical orbits. The elliptical equations are used for any of the above spacecraft array configurations in an earth locked one revolution per orbit (RPO) elliptic orbit only. One revolution per orbit spacecraft in a circular orbit will use circular orbit type equations. A spinning spacecraft in either an elliptic or circular orbit will use circular orbit type equations since the spin rate is uniform and not affected by the characteristic elliptical orbit

anomalies described later in this text. The computer program does not provide for checking spacecraft spin rates versus orbit types. Therefore, the program user must select either an elliptic or circular orbit using NCODE NTYPE. Elliptic orbits are used only when the spacecraft spin rate is 1 RPO.

Vector analysis of two separate coordinate systems, fixed and inertial, is the basis for calculating a panel incidence angle β at any time t . The panel incidence angle is defined as the angle between the sun vector and panel normal. Each coordinate system reference point (\hat{x} and \hat{x}' axes) may initially be parallel or separated by an angle ζ (NCODE ANGLO), which provides the program user with accurate real-time solar array calculations. For example, if solar array data is to be used in subsequent power system energy balance computations and a portion of the spacecraft orbit is in earth eclipse, then a real-time difference exists between the theoretical beginning of orbit referenced at start of eclipse in the energy balance program and beginning of daylight which is defined at time zero in the solar array program. The spacecraft reference point shall have shifted an amount equal to the eclipse duration in minutes (NCODE TN) times the spacecraft spin rate (NCODE DEGTOT) for circular one RPO orbits and spinning spacecrafts. Spin rates for one RPO elliptical orbit spacecraft are nonuniform and, therefore, special equations described later in this test must be used.

The first coordinate system is defined as the inertial system. The \hat{x} axis is referenced in the orbit at the start of earth eclipse and the \hat{z} axis is parallel to the orbit normal while the inertial system origin is located at the earth's center (Figure 2). Vector analysis of the sun vector \hat{s} in this system gives the following equation

$$\hat{s} = \sin \theta \cos \lambda \hat{x} + \sin \theta \sin \lambda \hat{y} + \cos \theta \hat{z}$$

where angle θ is the orbit normal to sun vector (NCODE ETA) and λ is the orbital phase angle referenced to the start of earth eclipse (NCODE TANGLE). λ is fixed with respect to time and is equal to half the angle ζ described above. If NCODE TANGLE is initialized to -1.0, the computer will automatically calculate λ . Either or both NCODES ANGLO and TANGLE may be initialized to -1.0.

Vector analysis of the second system which is fixed with respect to the spacecraft, (Figure 3) gives the following equation:

$$\hat{p} = \cos \phi \cos \epsilon \hat{x}' + \sin \phi \sin \epsilon \hat{y}' + \cos \hat{z}';$$

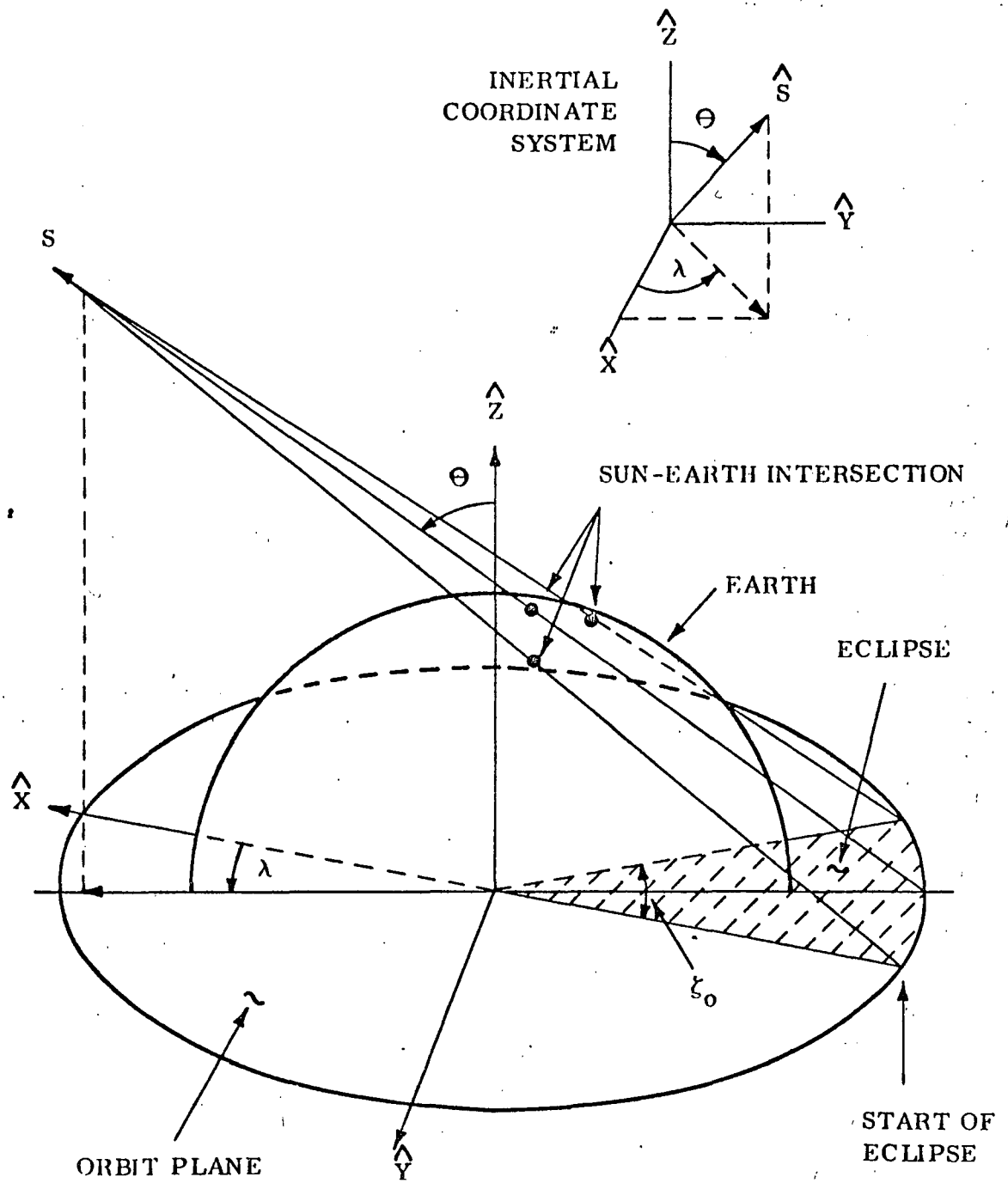


Figure 2. Inertial Coordinate System

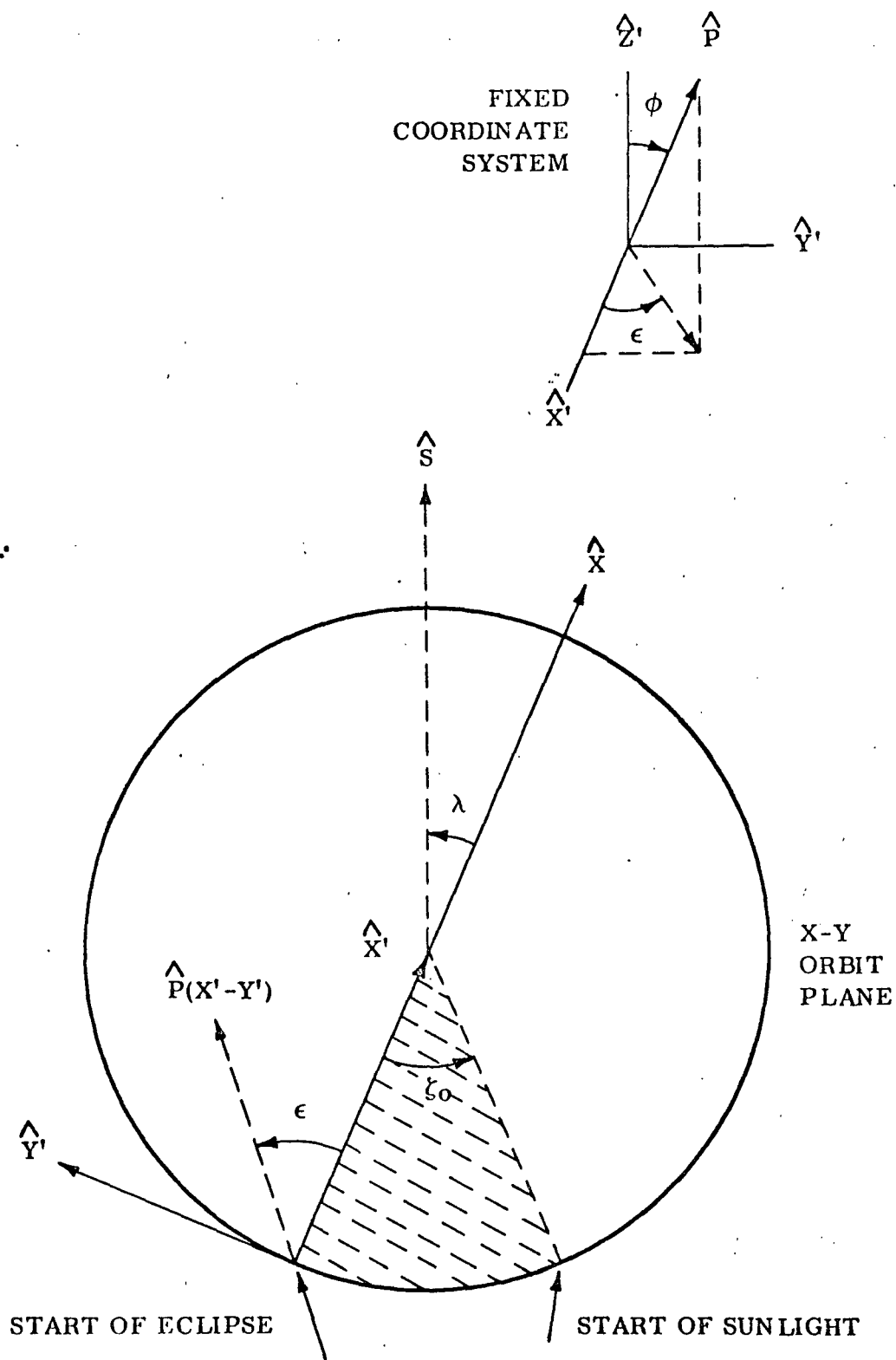


Figure 3. Fixed Coordinate System

where \hat{p} is the panel normal vector, ϕ is angle between \hat{p} and the spin axis, and ϵ is the angle between \hat{p} projected onto the orbit plane ($x' - y'$) and the spacecraft reference point. Figure 3 also shows the relationship of these two systems at time zero.

Turning the inertial coordinate system into the fixed system at any time t and solving for the cosine of the incidence angle β gives the following simplified relationship:

$$\beta = \cos^{-1} [\sin \theta \sin \phi \cos ((\epsilon + \zeta(t)) - \lambda) + \cos \theta \cos \phi]$$

where $\zeta(t)$ is defined as

$$\zeta(t) = \zeta_0 + w_s t, \text{ and}$$

w_s is the spin rate (NCODE DEGTOT) of the spacecraft in the degrees per minute. The above described general equation is used for panel incidence angle calculations of earth locked one RPO spacecraft in a circular orbit and spinning spacecraft in either a circular or elliptical orbit. This same equation is used for earth locked one RPO spacecraft in an elliptical orbit with one exception.

The rate of change of the spacecraft fixed reference point (x' axis) is non-uniform. Angle anomalies are introduced and dependent upon the orbit radius of apogee r_a (NCODE APOGEE) and perigee r_p (NCODE PERIGE). Therefore, $w_s t$ of $\zeta(t) = \zeta_0 + w_s t$ is defined in terms of the true anomaly ζ_e in the following relations.

$$\zeta(t) = \zeta_0 + \zeta_e \text{ and}$$

$$\zeta_e = \frac{\tan^{-1} \frac{(1-e^2)^{1/2} \sin E}{\cos E - e}}{\cos E - e}$$

where

$$e = \frac{r_a - r_p}{r_a + r_p} \quad (\text{orbit eccentricity})$$

$$E = M + e \sin E \quad (\text{eccentric anomaly})$$

$$M = \frac{2\pi}{P_0} t \quad (\text{mean anomaly})$$

$$t = \text{elapsed time}$$

$P_0 = TD + TN$ is the orbit period, TD is orbit daytime duration, and TN is the orbit nighttime duration.

The eccentric anomaly relationship is derived from the basic laws of Keplerian motion and is adequately called Kepler's equation. (Kepler's equation is more commonly shown as $M = E - e \sin E$.) In order to solve for the eccentric anomaly, an iterative Newton-Raphson formula is used and shown below.

$$E_{n+1} = E_n + \frac{M - E_n + e \sin E_n}{1 - e \cos E_n}$$

where

$E_1 = M$ and iterating until

$$\left| 1 - \frac{E_n}{E_{n+1}} \right| \leq \gamma, \text{ and}$$

where

γ is a tolerance set to 10^{-7} .

Selecting the type of spacecraft orbit is accomplished by means of NCODE NTYPE. This NCODE is automatically set by the computer. The program user shall call for elliptic orbit type computations only if he has a one RPO spacecraft in an elliptical orbit. Spacecraft spin rate (NCODE DEGTOT) is not used in elliptic orbit computations. NCODE NANG allows the program user to either compute panel incidence angles or call for a table lookup in STINT. Panel incidence angle versus time vs sun angle table numbers are recorded on panel description cards discussed in Section III of this report. Incidence angles which are calculated may also be printed out at the option of the program user by means of NCODE NWRIT.

SECTION III

USE OF PROGRAM

Assembly of the complete program as it is submitted to the computer is shown in Figure 4. This assembly basically consists of two parts -- a program deck and a data deck. The program deck, which can be used in either Fortran IV or binary form, is always used and is placed first in the assembly. It contains the MAIN routine and all of the subroutines used in the program (STINT, PHI, DEGRADE, STASH and INCANG) and does not require any card changes to perform its function.

The data deck contains all the numerical information the program requires for computation and defines the user-selected options for each run. Consequently, the data deck must be prepared specifically for each run, or series of chained runs, to be made. Cards and tables in the data deck must be positioned in the order shown in the program assembly in Figure 4. The data deck description and format are presented below in the proper assembly sequence.

A. DATE AND LIST OPTION CARD

Col. 1-2	Number of month
Col. 3-4	Number of day
Col. 5-6	Number of year
Col. 9	0 - Input data (STINT) tables not printed out
Col. 9	1 - Input data (STINT) tables printed out in exponential format

B. STINT TABLE TITLE CARD

Col. 1	Blank
Cols. 2-72	Any alpha-numeric information

PRECEDING PAGE BLANK NOT FILMED

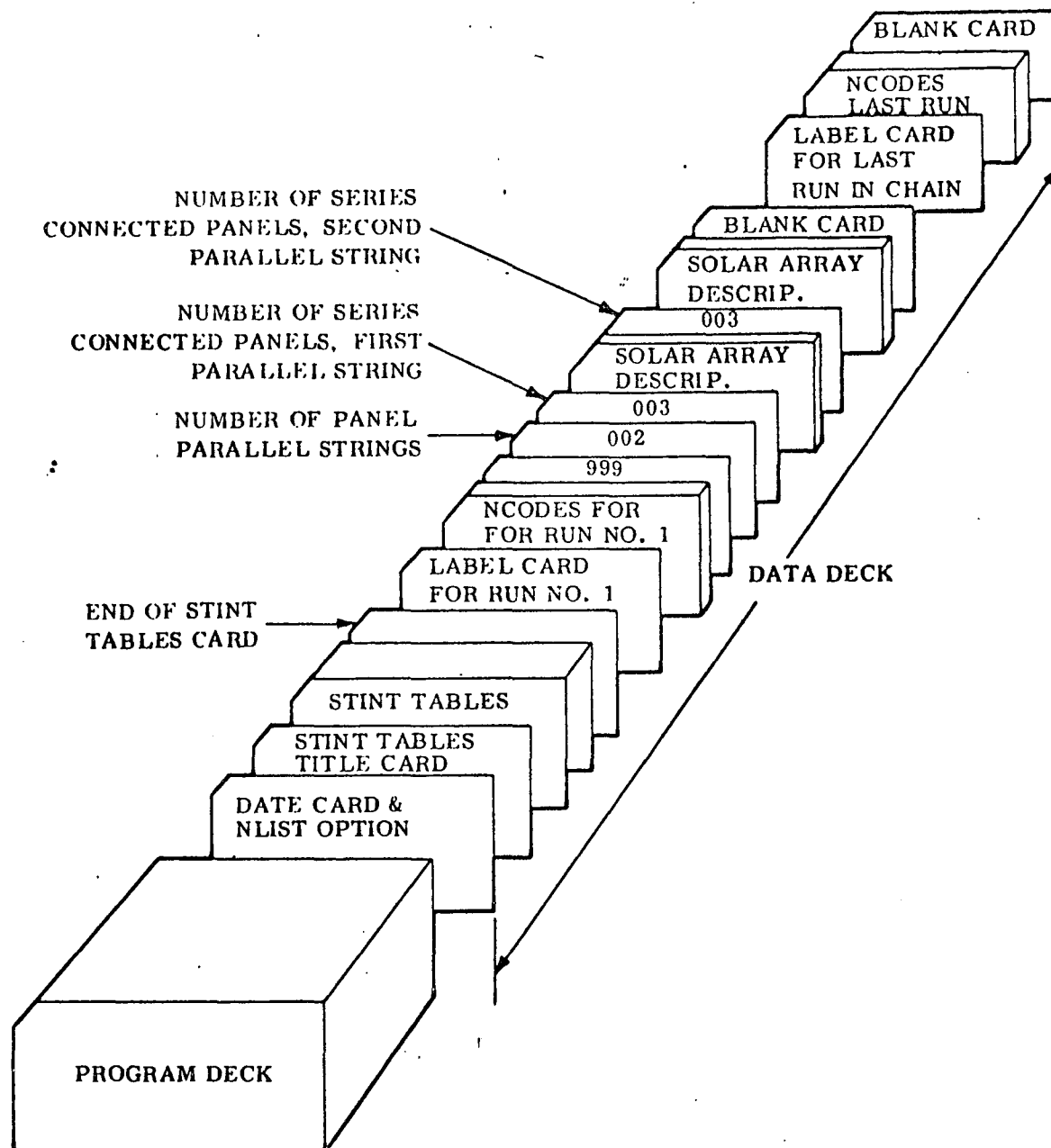


Figure 4. Program Assembly

C. STINT TABLES

The STINT tables are stacked one behind the other in the data deck in ascending numerical order. The 10 tables listed below must be presented in the data deck, in the order shown for each computer execution:

<u>Table No.</u>		<u>Table Name</u>
1		Solar Cell I-V curve
2		Relative Solar Array Current vs Incidence Angle vs cover glass thickness
3	(Variable Data)	Orbital Electrons Particle Flux
4		Orbital Protons Particle Flux
5		Solar Flare Proton Particle Flux
6		Solar Flare Alpha Particle Flux
7		Damage Factors for Electrons
8		Damage Factors for Protons
9		Damage Factors for Alpha Particles
10		NMVTBL Curve Shape Volts vs PHI

The maximum number of STINT tables that the program will accept is 200, the 10 tables listed above plus, starting with Table No. 11, a panel incidence angle versus time versus sun angle table and a temperature versus time versus sun angle table for each of the 75 panels comprising the solar array. If fewer than the maximum number (75) of panels is specified, fewer STINT tables are required. More than one panel may use the same angle or temperature table stored in STINT.

The first card of each STINT table is a header card, which must be prepared in the following format:

Cols. 1-8:	Any alpha-numeric characters can be used for a date
Cols. 9-12:	Table number. Cannot be zero. Fixed point and right justified
Cols. 13-14:	Number of argument ₁ values. Cannot be zero. Fixed point and right-justified

Cols. 15-16:	Number of argument ₂ values. Cannot be zero, is 1 for a function of one argument. Fixed point and right-justified
Cols. 17-19:	Not used
Cols. 20-70:	Any alpha-numeric characters desired. Usually used for table title
Cols. 71-72:	00

After the header card, each card in the table uses 10 fields of 7 columns each for the argument values and the function values. The first card contains the first nine argument₁ values in fields 2 through 10. In the following cards, field 1 contains an argument₂ value, and fields 2 through 10 contain corresponding function values. After all the argument₂ values have been spanned, the whole series of an argument₁ card followed by argument₂ cards can repeat until all the function values are used. If there is an argument₃ value for the table, it goes into field 1 of the argument₁ 1 card. Columns 71 and 72 on each card must contain a sequence number, starting with 01 for the first card. Figures 5 and 6 show typical STINT table coding sheets for a single argument (current as a function of voltage and computer data table 3) STINT table. Figures 7 and 8 show a two-argument STINT table format for computer data table 7, and a typical panel temperature table.

After the last STINT table in the data deck, there is a card labeled END OF STINT TABLES, starting in Col. 21. Cols. 9-12 and 71-72 must be left blank on this card.

D. RUN LABEL CARD

Following the END OF STINT TABLES card is a card containing any desired alpha-numeric information in cols. 2-72, which usually describes the first run to be made.

E. NCODE

Following the Run Label Card are the 37 NCODE cards. The card number, or NCODE, is right justified against col. 3. The numerical value of the NCODE variable is left-justified against col. 5 and must have a decimal point. Figure 9 shows the NCODE names, the NCODE numbers, the NCODE values and a brief description of each NCODE for a sample computer run. Only the NCODE (item) number and its numerical value are punched on the NCODE cards; the other data in Figure 9 are for information only. All 37 of the NCODEs are initially loaded

→ COL.20 NR BCL 30 DIG C, AND I-V CL'AVE

HEADER CARD	COLS 1-8	COLS 9-12	COLS 13-14	COLS 15-16	COLS 17-20	COLS 21-22	COLS 23-24	COLS 25-26	COLS 27-28	COLS 29-30	COLS 31-32	COLS 33-34	COLS 35-36	COLS 37-38	COLS 39-40	COLS 41-42	COLS 43-44	COLS 45-46	COLS 47-48	COLS 49-50	COLS 51-52	COLS 53-54	COLS 55-56	COLS 57-58	COLS 59-60	COLS 61-62	COLS 63-64	COLS 65-66	COLS 67-68	COLS 69-70	COLS 71-72	COLS 73-74	COLS 75-76	COLS 77-78	COLS 79-80	COLS 81-82	COLS 83-84	COLS 85-86	COLS 87-88	COLS 89-90	COLS 91-92	COLS 93-94	COLS 95-96	COLS 97-98	COLS 99-100																																																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100

[illegible]

Figure 5. Sample Coding Sheet Showing Format for a Single Argument STNT Table

COL. 20 ELECTRON FLUX FORMAT

HEADER CARD COLS 1-8 (TBL. DATE)										COLS 9-12 (TBL. NO.)										COLS 13-14 (TBL. NAME)										COLS 15-16 (SN)										COLS 17-22 (TBL. NAME)										COLS 23-30 (PDR)																													
FIELD 1					FIELD 2					FIELD 3					FIELD 4					FIELD 5					FIELD 6					FIELD 7					FIELD 8					FIELD 9					FIELD 10					SEQ. PROGRAM																													
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68												

COL 20 DAMAGE FACTORS FOR ELECTRONS

HEADER CARD COLS 1-8 09-30-69 (TBL. DATE) COLS 9-12 0007 (TBL. NO.) COLS 13-14 11 (TBL. NO.) COLS 15-16 06 (TBL. NO.) COLS 17-22 000 (TBL. NAME) COLS 73-77 (PONT) COLS 78-80 (PONT)

FIELD 1 • INTEGER • EXP	FIELD 2 • INTEGER • EXP	FIELD 3 • INTEGER • EXP	FIELD 4 • INTEGER • EXP	FIELD 5 • INTEGER • EXP	FIELD 6 • INTEGER • EXP	FIELD 7 • INTEGER • EXP	FIELD 8 • INTEGER • EXP	FIELD 9 • INTEGER • EXP	FIELD 10 • INTEGER • EXP	SEQ. PROGRAM NO. DECK NO.
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80										
1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
3.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6
4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
4.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8
5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9
5.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1
6.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2
7.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3
7.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4

Figure 7. Sample Coding Sheet Showing Format for a Two-Argument STINT Table

Figure 8. Sample Coding Sheet Showing Format for a Two-Argument STINT Table

NO.	WRITE ITEM DESCRIPTIONS ACROSS	ITEM NO.	VARIABLE	RUN COMMENTS OR		VARIABLE	DESCRIPTION	
	TD	1	100.0					
	DELTA T	2	1.0					
	SIG TSC	3	0.00014					
	SIG VOC	4	0.00024					
	DI 1	5	90.0					
	DI 2	6	100.0					
	DI 3	7	100.0					
	DI 4	8	100.0					
	DV 1	9	95.0					
	DV 2	10	100.0					
	AVP M0	11	0.460					
	ALP M0	12	0.113					
	AVO C0	13	0.577					
	THE TA	14	95.0					
	TNCT	15	30.0					
	ADIDE	16	1.0					
	DELT I	17	10.0					
	ADD T	18	40.0					
	FLUX	19	-1.0					
	CG	20	4.0					
	BS	21	15.0					
	ROHNS	22	1.0					
	NDGRAD	23	1.0					
	NEND	24	2.0					
1		2	3	4	5	6	7	8
9	10	11	12	13	14	15	16	17
18	19	20	21	22	23	24	25	26
27	28	29	30	31	32	33	34	35
36	37	38	39	40	41	42	43	44
45	46	47	48	49	50	51	52	53
54	55	56	57	58	59	60	61	62
63	64							

Figure 9. Format and Description of NCODES (Sheet 1 of 2)

into memory, thus a single run or the first of a series of chained runs must contain all the NCODE's in the data deck. Each of the NCODE's listed in Figure 9 are described below:

1. TD is the orbit suntime duration in minutes.
2. DELTAT is the desired orbital time increment between solar array calculations starting at zero minutes. Up to a maximum of 100 solar array I-V curves may be printed out for each run.
3. SIGISC is the input solar cell short-circuit current temperature coefficient expressed in amperes per degree centigrade.
4. SIGVOC is the input solar cell open-circuit voltage temperature coefficient expressed in volts per degree centigrade and is punched on the card as a positive number. The computer program will automatically assign the proper negative sign.
5. DI 1 is a short-circuit current degradation factor.
6. DI 2 is a short-circuit current degradation factor.
7. DI 3 is a short-circuit current degradation factor.
8. DI 4 is a short-circuit current degradation factor.
9. DV1 is a maximum power point voltage degradation factor.
10. DV2 is a maximum power point voltage degradation factor.
11. AVPMO is the input solar cell maximum power point voltage.
12. AIPMO is the input solar cell maximum power point current.
13. AVOCO is the input solar cell open-circuit voltage.
14. THETA is the open-circuit voltage degradation factor.
The DI's, DV's, and THETA are used for some of the following reasons:

<u>Reason</u>	<u>Effect</u>
Standard Cell Error	ISC*
Illumination Intensity Variation	ISC
Measurement Error	ISC
Ultraviolet Degradation	ISC

* short-circuit current

<u>Reason</u>	<u>Effect</u>
Series Wiring Loss	VPM*
Thermal Cycling Degradation	VPM
Voltage Measurement Error	OCV**

15. TNOT is the input solar cell reference temperature.
16. ADIODE is the panel series string isolation diode drop specified by the user. A value of 0.0 is punched if no isolation diode drop is desired in the output solar array curves.
17. DELTT is the temperature increment between solar cell I-V curve calculations in subroutine STASH.
18. ADDT is the difference in temperature between the highest STASH temperature and TNOT.
19. FLUX is punched as 0.0 if no charged particle irradiation damage is to be considered, in which case subroutines PHI and DEGRAD do not compute. If FLUX has a value of 1-MeV equivalent flux (Example: 2.6×10^{14} is punched as 26000000000000.0 on the card) subroutine PHI is bypassed and MAIN will calculate the mission flux based on DAYS. Subroutine DEGRAD will then degrade the solar cell for the mission 1-MeV flux. If flux is given a value of -1.0, subroutine PHI will compute a value of 1-MeV flux from tables of omnidirectional particle fluxes that the user must supply in table locations 3, 4, 5 and 6. This value of 1-MeV flux will be multiplied by the number of days specified in NCODE DAYS and will then be automatically sent to subroutine DEGRAD for the appropriate solar cell corrections.
20. CG is the solar cell cover glass thickness in mils of fused silica.
21. BS is the solar cell backshielding thickness in equivalent mils of aluminum.
22. BOHMS is the input solar cell base resistivity.
23. NDGRAD must be set to 1.0 in the first run. This causes the machine to automatically degrade the solar cell and expand it for temperature in subroutine STASH as specified by the degradation and temperature parameters in the NCODES. When chaining additional runs, if the solar cell degradations are not changed, NDGRAD should be set to 0.0 in the second run. By setting NDGRAD to 0.0 needless repetitive computations in the solar cell subroutines are eliminated.

* maximum power point voltage

** open-circuit voltage

24. NEND must be set to either 1.0, 2.0, 3.0 or 4.0 for each run, and determines which of the following options is selected:

NEND = 1.0	Do solar cell calculations only (PHI, DEGRAD and STASH) and stop.
NEND = 2.0	Do solar cell calculations and read new set of run instructions.
NEND = 3.0	Do solar cell and solar array calculations and stop.
NEND = 4.0	Do solar cell and solar array calculations and read new set of run instructions.

25. DAYS is the total number of mission days. This value is used to set the daily 1-MeV flux calculated in PHI to total mission flux when NCODE 19 is set to -1.0. Equivalent fluxes greater than 0.0 set in ENCODE 19 are also converted to total mission fluxes. DAYS should never be set to 0.0.
26. PBYPAS is the voltage drop of all series panel bypass diodes. A value of 0.0 is punched if no bypass diode drop is desired.
27. ANGLO is the angle between the two coordinate system reference points at time zero. This allows the program user to arbitrarily set the spacecraft reference point at any time in the orbit. It is normally used when a portion of orbit nighttime is encountered. The orbit will always start at the start of nighttime (eclipse). A value of -1.0 is used for automatic calculation of ANGLO by the program.
28. ETA is the angle between the sun vector and the normal to the orbital plane (or spacecraft spin axis).
29. TANGLE is the orbital phase angle referenced to the start of eclipse. A value of -1.0 may be used for automatic calculation by the program.
30. DEGTOT is the spacecraft spin rate and is used when circular orbital calculations are called for by NTYPE.
31. APOGEE is the elliptic orbit radius of apogee including the earth's radius.
32. PERIGE is the elliptic orbit radius of perigee including the earth's radius.
33. NTYPE is used to select the type of orbit. 0.0 is punched when a circular orbit is desired or when the spacecraft spin rate (DEGTOT) is greater than 1 RPO.

34. NANG allows the program user to call for panel incidence angle calculations (punched as 1.0) or for a panel incidence angle lookup in STINT (punched at 0.0).
35. NWRIT is used to printout calculated panel incidence angles and is punched as 1.0. If no print out is required, 0.0 is punched on the card.
36. NPUNCH is used to punch the solar array I-V curves on cards in a STINT tables format, and is punched as 1.0. If no array STINT tables are required 0.0 is punched on the card. STINT table sequence numbers are punched in columns 71, 72, and 73.
37. TN is orbit nighttime duration in minutes.

F. ARRAY SIGNAL CARD

If NCODE 24 has been punched with a 3.0 or a 4.0 immediately following the NCODE 37 card must be a card containing 999 in columns 1-3. This card tells the computer that solar array information is to follow.

G. NPARST (No. of Panel Parallel Strings)

Following the Array Signal Card is the NPARST card, which contains the number panel series strings connected in parallel in the array (maximum number of parallel strings is 25). This number must appear right justified in columns 1-3. A decimal point is not required.

H. NPANEL (No. of Series Panels)

Following the NPARST card is the NPANEL card, which contains the number of series panels in the first panel parallel string of the array (maximum number of series panels is 3*). This number must appear right justified in columns 1-3. No decimal point is required.

I. PANEL DESCRIPTION CARDS

Following the NPANEL card is a panel description card for each solar panel in the first parallel string. The number of these panel description cards must agree with the value of NPANEL. Each card contains six fields of ten columns each, in floating point format (requires decimal point).

* Panels connected in series shall have the same number of solar cells connected in parallel on each panel.

<u>Columns</u>	<u>Variable</u>	<u>Typical Value</u>
1-10	No. of Series-Connected Solar Cells per Panel	30.0
11-20	No. of Parallel Strings per Panel	10.0
21-30	Panel Angle to Spacecraft Spin Axis (Φ)	45.0
31-40	Panel to Spacecraft reference pt. (ϵ)	0.0
41-50	Panel Incidence Angle vs Time vs Sun Angle Table Location in STINT	11.0
51-60	Panel Temperature vs Time vs Sun Angle Location in STINT	12.0

Following the Panel Description Cards is another NPANEL card describing how many series panels are in Parallel String No. 2. The number of panel description cards following the NPANEL card must equal the value of NPANEL. This sequence is repeated for each parallel string. The number of NPANEL cards must agree with the value of NPARST.

Following the Panel Description Cards is a blank card. This tells the computer to stop reading in data and to start computing. If it is desired to chain an additional run, a new Run Label Card and only those NCODES and Panel Description Cards that contain changed or new information should be placed after the blank card. As many runs as are desired can be chained in this manner, ensuring that each new run starts with a Run Label Card and ends with a blank card. Refer again to Figure 4 for the proper sequence of card positions for chained runs. Figure 10 shows the format for the Array Signal Card, NPARST card, two NPANEL cards and six Panel Description cards.

Figure 10. Format and Description of Array Cards

SECTION IV

OUTPUT DATA DESCRIPTION AND FORMAT

The information that the computer prints out after a run consists of the following items:

(1) STINT Table Listing Option

There is an option in the program to list all the STINT tables. This is done by taking the data card at the beginning of the data package and either punching a one (1) or a zero (0) in column 9. Punching a one (1) will produce a listing of the STINT tables in an E format. A zero (0) will not produce a listing of the STINT tables.

(2) Input Data Page

- (a) Run number and date.
- (b) Run comments as specified on input card.
- (c) Listing of NCODE numbers, names and values.
- (d) Number panel parallel strings.
- (e) Panel parallel string number.
- (f) Solar array description: panel number, number of series solar cell rows, number of parallel solar cell strings, panel angle to spin axis, panel angle to SC reference point, number of STINT table which contains the panel incidence angle, number of STINT table which contains the panel temperature-time profile.

(3) Subroutine PHI (The fluxes are in equivalent 1-MeV electrons/cm².)

- (a) The computed electron flux
- (b) The computed proton flux
- (c) The computed solar flare proton flux
- (d) The computed solar flare alpha particle flux
- (e) The computed total daily flux
- (f) The computed total mission flux

(4) Subroutine DEGRAD

- (a) The solar cell I-V curve irradiation degraded
- (b) Short-circuit current
- (c) Current at the maximum power point
- (d) Open-circuit voltage
- (e) Voltage at the maximum power point

(5) Subroutine STASH

Values of temperature for which the degraded solar cell I-V curve has been prepared are listed in a row across the page. Values of maximum-power voltage and current, open-circuit voltage and short-circuit current appear in columns under each temperature. Values of every other calculated current and voltage pair comprising the I-V curve and stored in the computer memory are listed in columns under each temperature.

(6) Solar Array Data

- (a) Time in orbit sunlight (up to 100 time increments starting with 0.0 min.)
- (b) Array short-circuit current
- (c) Array open-circuit voltage
- (d) Maximum power
- (e) Maximum power current
- (f) Maximum power voltage
- (g) Solar array voltage in 1-volt steps from 0 volts up to 100 volts
- (h) Total solar array current at each voltage above for each time increment; a maximum of 100 solar array I-V curves can be produced per computer run.

(7) Panel Incidence Angle Data

- (a) Time
- (b) Panel parallel string number
- (c) Panel number (1, 2, or 3)
- (d) Incidence angle

(8) Solar Array STINT Table

- (a) Header Card with number of argument₁ and argument₂ values.
- (b) Voltage versus current versus time data cards. STINT table sequence numbers are also punched on the data cards in columns 71, 72, and 73.

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SECTION V

REFERENCES

1. Rasmussen, R., "Calculation of 1-MeV Electron Flux and Irradiation Degradation of Solar Cell I-V Curves by Computer," presented at the Sixth Photovoltaic Specialists Conference, Cocoa Beach, Fla., March 28-30, 1967.
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3. Harmon, H. and Rasmussen, R., "Temperature, Illumination Intensity and Degradation Factor Effects on Solar Cell Output Characteristics," presented at the IEEE Aerospace and Electronic Systems Conference, Seattle, Wash., July 1966.

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